JENRM, Vol. I, No. 1, 13-18, 2014
Research Article

Evaluation of landfill leachate management systems in Ghana

Kodwo Beedu Keelson*

Abstract
This paper presents an evaluation of landfill leachate management systems at three waste disposal sites in the wet equatorial climatic zone of Ghana. This particular climatic zone experiences the highest annual rainfall in the country. It was observed during walkover surveys that none of the waste disposal sites had any active or passive leachate management systems. It was also seen and demonstrated through computer simulations that the highest leachate flows occur during the months of June and October. Groundwater pollution, vadoze zone pollution, soil contamination and human health risks at all the locations were characterised as high. However surfacewater pollution risks were considered as low due the fact that there is adequate buffer distance from the Pra and Ankobra rivers to each of these individual dumpsites. The significance of this study is that it will provide guidance to decision makers and technical officers in other municipalities and districts within this climatic zone.

Keywords
waste disposal — groundwater pollution — surface water pollution — dumpsites

*, *Department of Civil Engineering, Kaaf University College*
***Corresponding author**: kodwobeedu@yahoo.com

Content

Introduction

Landfill leachate is defined as the liquid that has percolated through solid waste and has extracted dissolved or suspended materials [1]. Leachate is generated either from external water or from within the waste mass. The external water sources include precipitation, surface water run-on and ground water interflow. Leachate needs to be controlled in a landfill for the following reasons [2, 3]: to reduce the potential for seepage out of the landfill through the sides or the base either by exploiting weaknesses in the liner or by flow through its matrix; to prevent liquid levels rising to such an extent that they can spill over and cause uncontrolled pollution to ditches, drains, watercourses etc.; to influence the processes leading to the formation of landfill gas, chemical and biological stabilisation of the landfill; to minimise the interaction between the leachate and the liner; and in the case of above ground landfill, to ensure the stability of the waste. In Ghana the use of landfilling is still the preferred option for waste disposal in all the metropolitan areas, municipalities and districts. The siting of landfill sites, often, do not follow any planning considerations and lead to foul smells and flies in the rainy season, continuous smoke from smouldering fires, and a pollution of nearby water bodies. These open dumps still pose environmental hazards even after waste disposal activities have ceased at those locations. Research studies on abandoned waste disposal sites in Accra by [4, 5, 6] show that leachate samples have high concentration of nutrients and polycyclic aromatic hydrocarbons. Significant concentrations of heavy metals such as iron, zinc and aluminium were also observed. The wet equatorial climatic zone in Ghana experiences the highest annual rainfall and as such is much more susceptible to the adverse effects of uncontrolled leachate release arising from the lack of adequate leachate and surface water management systems. The aim of this research paper was to undertake an evaluation of existing leachate management systems at three waste disposal sites in the equatorial climatic zone of Ghana. It involved the collection of field data and the development of computer models to assess the hydrologic performance of existing systems. Some concluding thoughts are then put forward on how these waste disposal sites can be upgraded to minimize the impact of leachate flows during and after their useful design life

1. Materials and Methods

1.1 Description of Study Sites

Three waste disposal sites in the Central and Western Regions shown in Figure 1 were visited during the study. These disposal sites are Bompieso Dumpsite in the Tarkwa Nsuaem Municipal Area, Mfoum Dumpsite in the Upper Denkyira East Municipal Area and the Axim Dumpsite in the Nzema East Municipal Area. The three sites lie within the wet equatorial climatic zone in Ghana which has mean annual rainfall ranging between 1400mm – 2000mm.

1.2 Data collection

Primary data was collected through field investigations and face-to-face interviews with relevant resource persons. Secondary data were obtained from academic journals, technical publications, and internet sources. Data on existing leachate and surfacewater management infrastructure was obtained by means of a walkover surveys at the various waste disposal sites. A hand held GPS was used to obtain the geographic coordinates of various sites. Interviews were conducted with the municipal environmental health and planning officers at the various municipal assemblies. Information on day-to-day waste disposal site activities was obtained from officials of the Zoomlion Ltd, a local firm which is responsible for landfill site operations in Ghana. Discussions were held with either scavengers or residents living close to these disposal sites on issues regarding the nature, frequency and impacts of leachate flows. An extensive review of literature on all the study sites with respect to the regional and site specific hydrologic, geological, seismic characteristics was also done.

1.3 GIS-based spatial analysis

The Map Window GIS software was used to process the GPS data obtained during the walkover surveys. MapWindow GIS is an extensible open source geographic information system developed by the Idaho State University Geospatial Software (`http://www.mapwindow.org/`). This software has map querying features which allow the user to calculate areas and distances between user-defined points on a map. The geoprocessing tasks involved importing the GPS survey points into base maps in order to determine buffer distances from water bodies, areas of high groundwater level, and ecological and cultural heritage sites.

1.4 Water balance analysis

The Thornthwaite water-balance computer program was used to conduct a water balance analysis for the various waste disposal sites. This computer program which was developed by the U.S. Geological Survey [7] analyses the allocation of water among various components of the hydrologic system using a monthly accounting procedure. This procedure for estimating landfill water balance provides a faster method for analysis compared to the HELP Model due to its minimal site specific input data requirements [3, 8]. The required input data includes monthly precipitation and temperature values, runoff factor, direct runoff factor, soil-moisture storage capacity, latitude of location, rain temperature threshold, snow temperature threshold and maximum snow-melt rate. Table 1 and Table 2 show the mean monthly rainfall and temperature values respectively for the various locations [9, 10]. The output simulation results include the actual evapotranspiration, potential evapotranspiration, direct runoff, runoff, soil moisture storage and percolation.

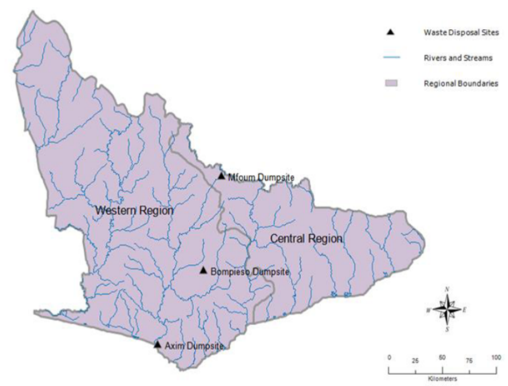

Figure 1. Location map of the study sites

Table 1. Mean monthly rainfall at waste disposal sites

	Rainfall(mm)		
Month	Axim	Bompieso	Mfoum
January	34	29	13
February	66	91	62
March	130	154	143
April	175	184	165
May	345	231	205
June	505	293	238
July	179	156	145
August	80	91	82
September	95	182	181
October	169	212	177
November	137	167	98
December	70	86	37

Water balance simulations were done for four different soil types namely sandy loam, silty loam, clay loam and clay. The soil moisture storage capacities for the various soil types which are shown in Table 3 were computed by multiplying an assumed landfill cover depth of 600 mm with the available water which is the difference between the field capacity and wilting point. The theoretical basis for the determination of leachate quantities using the Thornthwaite water balance analysis method is outlined in [11]. Water which is being routed through a waste disposal site basically consists of two phases; routing through the soil cover and routing through the compacted solid waste beneath. This research study only

Table 2. Mean monthly temperatures at waste disposal sites

	Mean Temperature ^{0}C		
Month	Axim	Bompieso	Mfoum
January	26.6	26.1	26.1
February	27.2	26.9	27.6
March	27.7	27.5	27.9
April	27.6	27.2	27.6
May	26.9	26.6	27.2
June	25.7	25.5	26.4
July	25.3	24.5	25.4
August	24.5	23.9	25.1
September	25.0	24.5	25.6
October	25.9	25.5	26.4
November	26.5	26.1	26.7
December	26.8	26.4	26.6

Table 3. Mean monthly temperatures at waste disposal sites

Soil Type	Moisture Storage Capacity (mm)
Sandy Loam	90
Silty Loam	120
Clay Loam	150
Clay	180

considered routing through the soil cover due to the lack of information on the depth of the various dumpsites.

2. Results

2.1 Current operational status

The three dumpsites are operational and receive solid waste from the respective municipal area capitals. All the sites can be categorized as open dumps. The Axim dumpsite shown in Figure 2 is located on the right–of-way of a major gas pipeline which is being constructed in the Western Region. The Mfoum dumpsite shown in Figure 3 is located on the right–of-way of the Ghana Grid Company high voltage transmission towers. The Bompieso dumpsite shown in Figure 4 does not have any conflicting land use issues.

2.2 Existing leachate management systems

Walkover surveys that were conducted at the Axim, Bompieso and Mfoum dumpsites showed that there were no existing leachate management-related site infrastructure and routine activities that are intended to reduce the generation, emission and environmental monitoring of leachate at any of these dumpsites.

Figure 2. Current conditions at the Axim dumpsite

Figure 3. Current conditions at the Mfoum dumpsite

Figure 4. Current conditions at the Bompieso dumpsite

2.3 Environmental risks and hazards

Soil contamination, groundwater and vadose zone pollution at the site were categorised as high due to the absence of landfill liners. Results from geoprocessing of the GPS data indicate that all the dumpsites are located within the catchment of the Pra and Ankobra river basins. The buffer distances from the dumpsites to any of the tributaries of these two river basins as shown in Figure 5 are greater than 1 kilometre. Consequently surfacewater pollution risks from the various dumpsites are classified as low. However leachate flows from these dumpsites could still pose a risk to domestic animals and livestock who drink contaminated water originating from dumpsite runoff. Human health risk are classified as high for settlements close to the dumpsite as a result of direct exposure to soils contaminated with leachate, inhalation of soil contaminants which have vaporised or consumption of potable water from leachate contaminated abstraction wells. The three dumpsites were also observed to have adequate buffer distance from sensitive ecological sites which are indicated as brown coloured polygons shown in Figure 6. This would seem to suggest that waste disposal activities at these sites would not pose a direct threat

to life and property there.

2.4 Water balance analysis results

Table 6, Table 7 and Table 8 presents the water balance analysis results for the Axim, Bompieso and Mfoum dumpsites respectively. The highest runoff estimates were obtained for the sandy loam cover soil whereas the highest evapotranspiration estimates were obtained for clay. Table 7, Table 8, and Table 9 show the monthly and seasonal variation of percolation for the different soil covers at the Axim, Bompieso and Mfoum sites respectively. These observations seem to suggest that peak leachate flows are to be expected in June and October which are the peak rainfall months in the major and minor rainy seasons respectively.

Table 4. Annual water balance estimates for Axim dumpsite

Description	Sandy loam	Silty loam	Clay loam	Clay
Precipitation(mm)	1985	1985	1985	1985
Runoff(mm)	786	779	767	750
Percolation(mm)	676	670	657	639

Table 5. Annual water balance estimates for Bompieso dumpsite

Description	Sandy loam	Silty loam	Clay loam	Clay
Precipitation (mm)	1876	1876	1876	1876
Runoff (mm)	652	650	639	622
Percolation (mm)	566	565	554	537

Table 6. Annual water balance estimates for Mfoum dumpsite

Description	Sandy loam	Silty loam	Clay loam	Clay
Precipitation (mm)	1546	1546	1546	1546
Runoff (mm)	375	368	357	341
Percolation (mm)	284	277	266	250

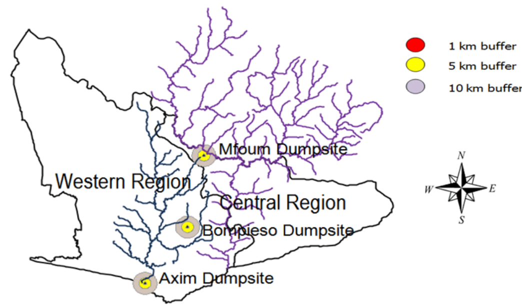

Figure 5. Buffer distances from the Ankobra and Pra river tributaries

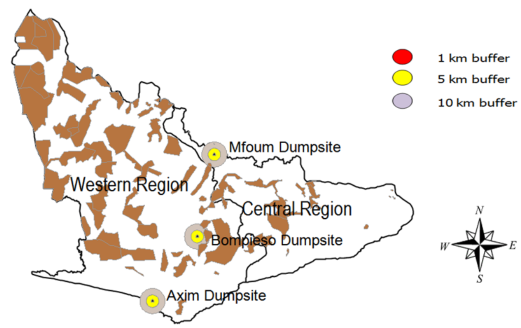

Figure 6. Buffer distances from sensitive ecological sites

Table 7. Monthly and seasonal variation of percolation for the Axim dumpsite(measurements in mm)

Month	SOIL TYPE			
	Clay	Clay Loam	Sandy Loam	Silty Loam
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	152.4	169.4	0	188.2
6	372.8	372.8	0	372.8
7	62.7	62.7	0	62.7
8	0	0	0	0
9	0	0	0	0
10	24.5	24.7	0	25.6
11	27	27	0	27
12	0	0	0	0

3. Discussions

Leachate management at Bompieso Dumpsite

The Bompieso dumpsite serves the Tarkwa township which has an estimated population of about 35,000 inhabitants. For such a small urban area the Ghana Landfill Guidelines [12] recommends the provision of at least an improved manual dumpsite. This site in its current state can still be used for a couple more years before it gets filled up. It is therefore necessary that it is

upgraded from an open dump to an improved manual dumpsite as stipulated in the technical guideline. The basic leachate management system that is prescribed for an improved manual dumpsite is the provision of a perimeter channels to collect and allow for infiltration of leachate into the ground media. The Bompieso dumpsite has adequate space for the construction of perimeter channels to intercept flows. These channels would typically be gravel-filled [1].

Leachate management at Axim and Mfoum dumpsites

The Axim and Mfoum dumpsites have a limited site lives by virtue of their peculiar conflicting land use issues. It may therefore not be justified in economic terms to construct new engineered systems. However leachate management should be one of the major priorities as part of a remediation and closure plan for both facilities. This is imperative because closed dumps may continue to pose environmental risks if adequate measures are put in place [5, 13]. The main leachate management system that must be provided as part of the closure plan is the placement of a final cover [1]. The final cover would typically have a thickness of between 400 – 600 mm. The regional soil groups in the Axim amd Mfoum dumpsites are oxisols and oxisols-ultisols respectively [14, 15]. The oxisols have a significant content of clay and as such may be suitable for use as a final cover as demonstrated in the water balance simulations. This may however not be the case for the oxisol-ultisol soil group in the Dunkwa area which contains a much lower content of clay.

Table 8. Monthly and seasonal variation of percolation for the Bompieso dumpsite(measurements in mm)

Month	SOIL TYPE			
	Clay	Clay Loam	Sandy Loam	Silty Loam
Jan	0	0	0	0
Feb	0	0	0	0
Mar	0	0	0	0
Apr	0	6.9	19.3	18.3
May	93.3	103.6	103.6	103.6
Jun	172.7	172.7	172.7	172.7
Jul	46	46	46	46
Aug	0	0	0	0
Sep	67.4	67.4	67.4	67.4
Oct	99.2	99.2	99.2	99.2
Nov	58	58	58	58
Dec	0	0	0	0

Table 9. Monthly and seasonal variation of percolation for the Mfoum dumpsite

Month	SOIL TYPE			
	Clay	Clay Loam	Sandy Loam	Silty Loam
Jan	0	0	0	0
Feb	0	0	0	0
Mar	0	0	0	0
Apr	0	0	0	0
May	4.6	20.3	38.5	31.7
Jun	113.3	113.3	113.3	113.3
Jul	28.8	28.8	28.8	28.8
Aug	0	0	0	0
Sep	43.1	43.1	43.1	43.1
Oct	60.5	60.5	60.5	60.5
Nov	0	0	0	0
Dec	0	0	0	0

4. Conclusion

This paper has presented an evaluation of leachate management systems at three waste disposal sites in the wet equatorial climatic zone of Ghana. None of the waste disposal sites had any active or passive leachate management systems. It was also observed during walkover surveys and through computer simulations that the highest leachate flows occur during the months of June and October. Groundwater pollution, vadoze zone pollution, soil contamination and human health risks at all the three locations were characterised as high. However surfacewater pollution risks were considered as low due the fact that there is adequate buffer distance from the Pra and Ankobra rivers to each of these dumpsites.The Bompieso dumpsite at Tarkwa would have to be provided with gravel filled channels in order to minimise the effects of leachate generation. The Axim amd Mfoum dumpsites have to be closed down as soon as practical and provided with a final soil cover. Recommendations for further study include a quantitative assessment of soil contamination and ground water pollution in Tarkwa by conducting laboratory testing of field samples.

Acknowledgments

The author would like to express their gratitude to the Kspyx Ltd/WastePro Software for use of their computer facilities.

References

[1] Rushbrook, P and Pugh, M. (1999).Solid waste landfills in low and middle income countries: A technical guide to planning, design and operation. *World Bank Technical Publication 426. World Bank.*

[2] Ireland EPA (2000). Landfill site design. Ireland Environmental Protection Agency. `http://www.epa.ie.` [Accessed 7^{th} July, 2012].

[3] WSDOE . (1987).Solid Waste Landfill Design Manual. Washington State Department of Ecology. Publication No. 87-13. `http://www.access.wa.gov` [Accessed 12^{th} July, 2012].

[4] DENUTSUI, D., ET AL. (2012). Leachate characterization and assessment of unsaturated zone pollution near municipal solid waste landfill site at Oblogo, Accra-Ghana. *Research Journal of Environmental and Earth Sciences*. 4(**1**): 134-141.

[5] OSEI, J., ET AL. (2011). The impact of Oblogo landfill site in Accra-Ghana on the surrounding environment. *Research Journal of Environmental and Earth Sciences.*, 3(**6**):633-636.633-636.

[6] ESSUMANG, D.K., ET AL (2009). Source assessment and analysis of polycyclic aromatic hydrocarbon (PAH's) at the Oblogo waste disposal sites and some water bodies in and around the Accra Metropolis of Ghana.*Journal of Water Resource and Protection.* , (**1**):456- 468.

[7] MCCABE, G.J.,and MARKSTROM, S.L.(2007). A monthly water-balance model driven by a graphical user interface *U.S. Geological Survey Open-File Report*, 2007-1008.

[8] SCHROEDER, P., ET AL. (1994). The Hydrologic Evaluation of Landfill Performance (HELP) engineering documentation for version 3. EPA/600R-64/168b. *U.S. Environmental Protection Agency Risk Reduction Laboratory. Cincinnati. Ohio.*

[9] GHANA HYDRO-DATABASE (2014a). Central Region Climate, Fact Sheet No. CLM-FF-CNR.`http://www.ghanahydrodata.com.` [Accessed 5th January, 2014]

[10] GHANA HYDRO-DATABASE (2014b). Western Region Climate, Fact Sheet No. CLM-FF-WR. `http://www.ghanahydrodata.com.` [Accessed 5th January, 2014]

[11] FENN, D.G., ET AL. (1975).Use of water balance method for predicting leachate generation from waste disposal sites. United States Environmental Protection Agency. Report No. EPA/530/SW-168. `http:/nepis.epa.gov.` [Accessed 5th July, 2012].

[12] GEPA (2002). Ghana Landfill Guidelines. *Ghana Environmental Protection Agency. Accra. Ghana.*

[13] USEPA (1988).Case studies on ground water and surface water contamination from municipal solid waste landfills. United States Environmental Protection Agency. Office of Solid Waste. Report No. EPA/530/SW-88-040. `http:/nepis.epa.gov.` [Accessed 6th July, 2012].

[14] OBENG, H. (2000). Soil classification in Ghana. Selected Economic Issues No. 3. Centre for Policy Analysis. Accra. Ghana.

[15] USDA (1999). Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys. 2nd Edition. Agriculture Handbook No. 436. *United States Department of Agriculture Natural Resources Conservation Service Washington D.C.*